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<b>TRANSMITTAL FORM</b>  (to be used for all correspondence after initial filing)	Application Number	10/600,258	
	Filing Date	June 20, 2003	
	First Named Inventor	MACCREADY, Paul B.	
	Art Unit	3644	
	Examiner Name	HOLZEN, Stephen A.	
Total Number of Pages in This Submission	42	Attorney Docket Number	AVI 1005-04US

ENCLOSURES (Check all that apply)		
<input checked="" type="checkbox"/> Fee Transmittal Form <input type="checkbox"/> Fee Attached <input type="checkbox"/> Amendment/Reply <input type="checkbox"/> After Final <input type="checkbox"/> Affidavits/declaration(s) <input type="checkbox"/> Extension of Time Request <input type="checkbox"/> Express Abandonment Request <input type="checkbox"/> Information Disclosure Statement  <input type="checkbox"/> Certified Copy of Priority Document(s) <input type="checkbox"/> Reply to Missing Parts/ Incomplete Application <input type="checkbox"/> Reply to Missing Parts under 37 CFR 1.52 or 1.53	<input type="checkbox"/> Drawing(s) <input type="checkbox"/> Licensing-related Papers  <input type="checkbox"/> Petition <input type="checkbox"/> Petition to Convert to a Provisional Application <input type="checkbox"/> Power of Attorney, Revocation Change of Correspondence Address <input type="checkbox"/> Terminal Disclaimer <input type="checkbox"/> Request for Refund <input type="checkbox"/> CD, Number of CD(s) _____ <input type="checkbox"/> Landscape Table on CD	<input type="checkbox"/> After Allowance Communication to TC <input type="checkbox"/> Appeal Communication to Board of Appeals and Interferences <input checked="" type="checkbox"/> Appeal Communication to TC (Appeal Notice, Brief, Reply Brief) <input type="checkbox"/> Proprietary Information <input type="checkbox"/> Status Letter <input checked="" type="checkbox"/> Other Enclosure(s) (please identify below): Credit Card Payment Form PTO-2038
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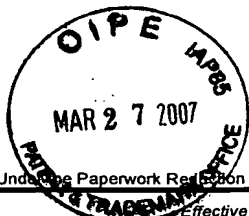
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Date	March 22, 2007	Reg. No.	39,694

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Signature	<i>John A. Griecci</i>		
Typed or printed name	John A. Griecci	Date	March 22, 2007

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# FEE TRANSMITTAL

## For FY 2007

☒ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT (\$) 250.00

**Complete if Known**

Application Number	10/600,258
Filing Date	June 20, 2003
First Named Inventor	MACCREADY, Paul B.
Examiner Name	HOLZEN, Stephen A.
Art Unit	3644
Attorney Docket No.	AVI 1005-04US

**METHOD OF PAYMENT (check all that apply)**

☐ Check ☒ Credit Card ☐ Money Order ☐ None ☐ Other (please identify): \_\_\_\_\_

☒ Deposit Account Deposit Account Number: 50-1809 Deposit Account Name: Law Office of John A. Griecci

For the above-identified deposit account, the Director is hereby authorized to: (check all that apply)

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**FEE CALCULATION****1. BASIC FILING, SEARCH, AND EXAMINATION FEES**

Application Type	FILING FEES		SEARCH FEES		EXAMINATION FEES		Fees Paid (\$)
	Fee (\$)	Small Entity Fee (\$)	Fee (\$)	Small Entity Fee (\$)	Fee (\$)	Small Entity Fee (\$)	
Utility	300	150	500	250	200	100	
Design	200	100	100	50	130	65	
Plant	200	100	300	150	160	80	
Reissue	300	150	500	250	600	300	
Provisional	200	100	0	0	0	0	

**2. EXCESS CLAIM FEES****Fee Description**

Each claim over 20 (including Reissues)

Each independent claim over 3 (including Reissues)

Multiple dependent claims

Fee (\$)	Small Entity Fee (\$)
50	25
200	100
360	180

Total Claims	Extra Claims	Fee (\$)	Fee Paid (\$)
- 20 or HP =	x	=	0

HP = highest number of total claims paid for, if greater than 20.

Indep. Claims	Extra Claims	Fee (\$)	Fee Paid (\$)
- 3 or HP =	x	=	0

HP = highest number of independent claims paid for, if greater than 3.

**3. APPLICATION SIZE FEE**

If the specification and drawings exceed 100 sheets of paper (excluding electronically filed sequence or computer listings under 37 CFR 1.52(e)), the application size fee due is \$250 (\$125 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

Total Sheets	Extra Sheets	Number of each additional 50 or fraction thereof	Fee (\$)	Fee Paid (\$)
- 100 =	/ 50 =	(round up to a whole number) x	=	0

**4. OTHER FEE(S)**

Non-English Specification, \$130 fee (no small entity discount)

Other (e.g., late filing surcharge): Appeal Brief under 37 CFR 41.20(b)(2), small entity

Fees Paid (\$)
0
250.

**SUBMITTED BY**

Signature		Registration No. (Attorney/Agent) 39,694	Telephone (310) 376-6527
Name (Print/Type)	John Griecci		Date March 22, 2007

This collection of information is required by 37 CFR 1.136. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 30 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

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Application No. : 10/600,258  
Appellants : MACCREADY et al.  
Filed : June 20, 2003  
Art Unit : 3644  
Examiner : HOLZEN, Stephen A.

Confirmation No. 7491

10

Docket No. : AVI 1005-04US  
Customer No. : 28327  
Date : March 22, 2007

15

Mail Stop: Appeal Brief - Patents  
Honorable Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

APPELLANTS' BRIEF

20

Dear Sir:

**I. REAL PARTY IN INTEREST**

25

The real party in interest in this application is assignee AEROVIRONMENT INC.

**II. RELATED APPEALS AND INTERFERENCES**

30

No appeal or interference known to Appellants or Appellants' legal representative will directly affect, or be directly affected by, or have a bearing on the Board's decision in the pending appeal.

35

**III. STATUS OF CLAIMS**

Claims 1-20 are pending in the application, and have been finally rejected by the Examiner. Appellants have appealed the rejection of claims 1-20. Claims 21-39 were canceled, without prejudice, in a prior amendment.

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#### **IV. STATUS OF AMENDMENTS**

Appellants have not filed an amendment after final rejection. Claims 1-20 stand as they were prior to the Examiner's final rejection.

5

#### **V. SUMMARY OF CLAIMED SUBJECT MATTER**

Independent claim 1 recites an aircraft having a fuel cell reacting a fuel (e.g., hydrogen) from a fuel source and an oxidizer (e.g., oxygen) from an oxidizer source. The aircraft uses a controller to regulate the reaction pressure of the reactants to be less than one atmosphere (i.e., 14.7 psia) when the aircraft is at a cruise altitude. The low reactant pressures of the present invention allow for the fuel cell system to have significantly less weight, which is of unique importance in the context of an aircraft power system.

15

In particular, the aircraft includes a fuel source (see, fuel tank 111, pg. 13, lines 1-6) having a mechanism to regulate delivery of the fuel (see, pg. 14, lines 16-23), an oxidizer source configured to provide an oxidizer, e.g., an inlet and compressor to compress ambient air (see, pg. 13, lines 8-19), and a fuel cell 131 configured to combine hydrogen from the hydrogen source and oxygen from the oxygen source at a given power-generation rate (see, pg. 12, lines 12-13) to generate power (see, pg. 14, lines 7-9).

20

The fuel cell is preferably configured to react the hydrogen and the oxygen at less than one atmosphere of pressure, and possibly down to 2-3 psia (see pg. 12, lines 22-28). To this end, the aircraft includes a controller configured to regulate the reaction pressure of either or both of the fuel and the oxidizer. As the aircraft ascends to cruise-level altitudes, the controller regulates the compression of ambient air to produce reaction pressures below 1 atmosphere (see pg. 15, line 4, to pg. 16, line 18). Such a configuration allows for a small, simple compressor and fuel cell, thus providing for stratospheric flight with lighter-weight and simpler fuel cell technology (see, pg. 8, lines 19-24, pg. 12, lines 22-28).

25

30

Claim 17 recites a number of features akin to those of claim 1. Furthermore, to provide adequate operation of the fuel cell while minimizing the compressor power usage

and necessary size (i.e., weight), and while protecting the integrity of the fuel cell, the fuel cell includes a control system configured to control the operation of the hydrogen source and the oxygen source for a given aircraft flight condition, such that the fuel cell reacts oxygen at a first reaction pressure with hydrogen at a second reaction pressure. The first  
5 reaction pressure (i.e., that of the oxygen) is less than one atmosphere. The difference between the first reaction pressure and the second reaction pressure is controlled to be no greater than a predetermined limit. See, pg. 16, lines 1-18. This allows for previously stored hydrogen to be provided at a higher pressure (and fuel density) than the presently compressed air, while limiting the differential such that it does not harm the fuel cell  
10 membrane.

## **VI. GROUNDS OF REJECTION TO BE REVIEWED ON APPEAL**

15           Ground 1.       Claims 1-20 were rejected under 35 U.S.C. § 103 as being unpatentable over Langford, III, U.S. Patent No. 5,106,035.

## **VII. ARGUMENT**

### **A) An Introduction to Fuel Cells**

20           In a typical hydrogen-fueled fuel cell, hydrogen and oxygen are received on opposite sides of a proton exchange membrane. Hydrogen ions (i.e., protons) pass  
25 through the membrane to the oxygen side of the membrane, leaving their electrons to pass from a fuel cell anode, through an external circuit containing an electric load (e.g., an aircraft electrical system) to a cathode on the oxygen side of the membrane. The hydrogen ions on the oxygen side combine with oxygen and the electrons on the cathode to produce water. As will be described below, high reaction pressures provide for higher  
30 densities of hydrogen and oxygen on opposite sides of the membrane, and thus improve fuel cell stack performance.

**B) An Introduction to Langford, III**

Appellants offer the following brief summary of Langford, III. Additional details of Langford, III will be discussed as necessary within the subsections of arguments against rejections of specific claims.

Langford, III discloses an aircraft that alternates between flying at lower altitudes of around 20 km (~65,000 ft.) and higher altitudes up to 40 km (~130,000 ft.). The aircraft derives its power from fuel cells that react a gaseous hydrogen fuel with gaseous oxygen. The hydrogen fuel is carried aloft in a high-pressure liquified form, and is used up throughout the flight. At the low altitudes, oxygen in the form of ambient air is collected, liquified and stored in pressurized storage tanks (an oxidizer reservoir) for use at high altitudes. At the high altitudes, this stored oxygen is provided by the pressurized storage tanks to the fuel cell. See, col. 2, lines 43-62, col. 3, lines 27-47, col 4, lines 46-56, and the Background of the Invention.

With reference to FIG. 2, it is at low altitudes that the liquified oxidizer is supplied to the oxidizer reservoir (see, col. 4, lines 46-48). More particularly, an inlet 206 collects ambient air, a heat exchanger/condenser 207 condenses the oxygen in the collected air, and a pump 208 compresses this condensed oxidizer for storage in the oxidizer reservoir 210. Optionally, a separator 209 may separate nitrogen from the condensed and compressed air for use in cooling the fuel cell 201. See, col. 4, lines 28-45.

While this is occurring (i.e., at low altitudes), ambient air is used as the source of the oxidizer for the fuel cell (see, col. 4, lines 46-48). More particularly, not all of the oxygen is condensed by the heat exchanger/condenser 207. A gas phase compressor 221 compresses the remaining air for delivery to the fuel cell 201. The fuel cell 201 receives this compressed air at approximately 50 psi. The fuel cell likewise receives the gaseous hydrogen at approximately 50 psi (see, col. 4, lines 13-16, 21-25 and 51-56). At higher altitudes the oxidizer is provided by the oxidizer reservoir 210 rather than the gas phase compressor 221 (see, col. 4, lines 19-23), as a compressor for use at those altitudes would prove prohibitively heavy and inefficient (see, col. 3, lines 33-37).

**C) Langford, III Fails to Render Claims 1-16 Unpatentable**

Claim 1 recites a controller configured to regulate the reaction pressure of a reactant of the group consisting of the fuel and the oxidizer, wherein the controller is configured to regulate the reaction pressure to be less than one atmosphere with the aircraft at a cruise altitude and the fuel cell operating at the given power-generation rate. Claims 2-16 depend from claim 1.

The Final Office Action, dated October 16, 2006 ("the Final Action"), acknowledges that Langford, III fails to disclose the fuel and oxidizer reaction pressures being regulated to less than one atmosphere (see, the Final Action, pg. 6, first paragraph). Instead, citing *In re Aller et al.*, 220 F.2d 454, 105 U.S.P.Q. 233 (C.C.P.A. 1955), the Final Action recites that "it would have been obvious to one having ordinary skill in the art at the time the invention was made to supply a gaseous reactant at a pressure less than one atmosphere, since it has been held that where the general conditions of a claim are disclosed in one prior art, discovering the optimum or workable ranges involves only routine skill in the art."

Moreover, the Final Action denies that Langford, III teaches away from a reaction pressure less than one atmosphere when the aircraft is in flight. Instead, the Final Action asserts that Langford, III discloses nothing as to the reaction pressure, despite the fact that Langford, III clearly recites that the reactants are injected into the fuel cell at 50 psi, with the oxidizer being compressed to this pressure solely for the purpose of being injected into the fuel cell.

As described below, Appellants respectfully traverse that the present invention is simply discovering the optimum or workable ranges in a manner that is routine skill in the art, rather than being a non-obvious development in technology. Thus, the Final Action fails to establish a *prima facie* case of obviousness. Moreover, Appellants respectfully reassert that Langford, III clearly teaches away from a reaction pressure less than one atmosphere.

**i) Claims 1-16: The Present Invention Is Not Simply Discovering the Optimum or Workable Ranges**

It is well understood in fuel cell design that higher pressure systems provide higher power density. See, Gelfi, Sylvain; Stefanopoulou, Anna G.; Pukrushpan, Jay T.; Peng, Huei, Dynamics of Low-Pressure and High-Pressure Fuel Cell Air Supply Systems, Proceedings of the American Control Conference, June 4-6, 2003, pg. 2049-2064, Denver, Colorado, USA. Indeed, "high operating pressure improves the fuel cell stack performance" (see, Gelfi et al., pg. 2049). The disclosure of Langford, III was prepared with the recognition that higher reaction pressures provide for more efficient fuel cell operation (see, col. 3, lines 39-41).

Because higher pressures improve fuel cell performance, the mere optimization of fuel cell operation would not lead a system designer to design a fuel cell system operating with reaction pressures below one atmosphere. Instead, this breakthrough is of value in that it allows a fuel cell to operate with a small, light compressor and a fuel cell having walls that don't have to maintain a large pressure differential with respect to the outside atmosphere. Such an advantage is particularly important for very lightweight aircraft, for which a difference in system weight is significant with respect to the aircraft weight. Thus, the advantage of the present invention is not that the fuel cell is more efficient than a high-pressure fuel cell, but rather that it allows for a high altitude aircraft of a more effective configuration.

The Final Action recites In re Aller et al. for the proposition that where the general conditions of a claim are disclosed in one prior art, discovering the optimum or workable ranges involves only routine skill in the art. However, in its written opinion, the In re Aller et al. court clarified that under some circumstances, range changes may produce results that are different in kind and not merely in degree, and thus may impart patentability (see, Aller et al., at 456, note 1). Appellants have identified such a range (i.e., a reaction pressure less than one atmosphere), and shown the unique advantages provided in the use of this range. More particularly, Appellants' application clearly recites and explains that the operation of a fuel cell at pressures down to less than one atmosphere provides for stratospheric flight with lighter aircraft weight and simpler fuel cell technology, even though the fuel cell operates at lower fuel cell stack performance levels.



Because the present invention is not simply discovering the optimum or workable ranges, but rather is a change producing results that are different in kind and not merely in degree, Langford, III fails to render claims 1-16 unpatentable. Appellants respectfully request the rejection of claims 1-16 be reversed.

5

**ii) Claims 1-16: Langford, III Teaches Away from a Reaction Pressure less than One Atmosphere**

As described above, Langford, III recites that low-pressure air is compressed in a compressor 221 and then the injected into the fuel cell (col. 4, lines 21-23) at approximately 50 psi (i.e., greater than 3 atmospheres) (col. 4, lines 13-16). Yet, the Final Action recites that Langford, III is silent as to the reaction pressure, and asserts that as a result, Langford, III does not teach away from a reaction pressure less than one atmosphere.

15

Langford, III discloses no other systems interacting with the compressed air between the compressor 221 and the fuel cell 201, and states that the compressor operates only at low altitudes. Moreover, Langford, III discloses no secondary reason for compressor 221 to raise the air pressure all the way to 50 psi, other than "to increase the pressure of the oxidizer to levels required for efficient fuel cell operation" (see, col. 3, lines 39-41).

Since the Langford, III compressor 221 serves only to raise the pressure of air being directly injected into the fuel cell, and since high reaction pressures in fuel cells improve fuel cell stack performance, Langford, III clearly teaches a reaction pressure that is more than triple a pressure of one atmosphere. Moreover, if the high pressure of the injected air were not used by the fuel cell, the weight and power requirements of the compressor 221 would be unnecessarily excessive, as the compressor 221 has no other function than to raise the oxidizer pressure to 50 psi. Such excesses are not logical for an aircraft-mounted power system.

30

Because the Langford, III patent discloses the use of a compressor configured to pressurize the oxidizer all the way to 50 psi, and discloses no intended use for that compressor or for the compressed air other than for "efficient fuel cell operation," the

Langford, III patent teaches away from a reaction pressure less than one atmosphere. Because Langford, III teaches away from a reaction pressure less than one atmosphere, it fails to render claims 1-16 unpatentable. Appellants respectfully request the rejection of claims 1-16 be reversed.

5

**C) Langford, III Fails to Render Claims 17-20 Unpatentable**

Claim 17 recites a control system configured to control the operation of the hydrogen source and the oxygen source at a given aircraft flight condition, such that the fuel cell reacts oxygen at a first reaction pressure, with hydrogen at a second reaction pressure. The first reaction pressure is less than one atmosphere, and the difference between the first reaction pressure and the second reaction pressure is no greater than a predetermined limit. Claims 18-20 depend from claim 17.

The Final Action fails to identify a controller configured to regulate the differential pressures as claimed. Moreover, as discussed above, the Final Action recites that it would have been obvious to one having ordinary skill in the art at the time the invention was made to supply a gaseous reactant at a pressure less than one atmosphere, and denies that Langford, III teaches away from a reaction pressure less than one atmosphere when the aircraft is in flight.

As described below, Appellants respectfully traverse that the Final Action identifies a controller configured to regulate the pressures as claimed, and further respectfully traverse that the present invention is simply discovering the optimum or workable ranges in a manner that is routine skill in the art, rather than being a non-obvious development in technology. Thus, the Final Action fails to establish a *prima facie* case of obviousness. Moreover, Appellants respectfully reassert that Langford, III teaches away from a reaction pressure less than one atmosphere.

**i) Claims 17-20: Langford, III. Fails to Disclose the Claimed Control System**

Claim 17 recites "a control system configured to control the operation of the hydrogen source and the oxygen source at a given aircraft flight condition such that the fuel cell reacts oxygen at a first reaction pressure with hydrogen at a second reaction pressure, wherein the first reaction pressure is less than one atmosphere, and wherein the difference between the first reaction pressure and the second reaction pressure is no greater than a predetermined limit" (emphasis added).

Langford, III fails to disclose a fuel cell operating with a differential pressure, and further fails to disclose a control system configured to actively control that differential. The present invention allows for the use of a differential pressure, thereby providing for the compressor to be sized and operated at minimum levels, while advantageously meeting power needs with the available fuel.

Because Langford, III fails to disclose a control system configured to regulate pressure differentials between the fuel and oxidizer, the § 103 rejection of claims 17-20 is improper and Appellants request it be reversed.

**ii) Claims 17-20: The Present Invention Is Not Simply Discovering the Optimum or Workable Ranges**

Claims 17-20 provide for "a control system configured to control the operation of ... the oxygen source ... such that the fuel cell reacts oxygen at ... less than one atmosphere." As described above with reference to claims 1-16, it is well understood in fuel cell design that higher pressure systems provide higher power density. The advantage of the present invention is not that the fuel cell is more efficient than a high-pressure fuel cell, but rather that it allows for a high altitude aircraft of a more effective configuration.

Under the reasoning recited above with respect to claims 1-16, the present invention is not simply discovering the optimum or workable ranges, but rather is a change that is different in kind and not merely in degree. Therefore, Langford, III fails to

render claims 17-20 unpatentable. Appellants respectfully request the rejection of claims 17-20 be reversed.

**iii) Claims 17-20: Langford, III Teaches Away from the Oxygen Reaction Pressure Being Regulated to less than One Atmosphere**

As described above with reference to claims 1-16, Langford, III clearly teaches a reaction pressure that is more than triple a pressure of one atmosphere. Moreover, if the high pressure of the injected air were not used by the fuel cell, the weight and power requirements of the compressor 221 would be unnecessarily excessive, as the compressor 221 has no other function.


Because the Langford, III patent teaches away from a fuel cell that reacts oxygen at a pressure less than one atmosphere, as described above with reference to claims 1-16, Langford, III fails to render claims 17-20 unpatentable. Appellants respectfully request the rejection of claims 17-20 be reversed.

**C) CONCLUSION**

For the reasons set forth above, the rejection of claims 1-20 is improper and should be reversed. A decision directing the Examiner to issue a Notice of Allowance is respectfully requested.

Respectfully submitted,

The Law Office of John A. Griecci

By   
John A. Griecci  
Registration No. 39,694

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## VIII. CLAIMS APPENDIX

1. An aircraft, comprising:

a fuel source configured to provide a fuel;

5 an oxidizer source configured to provide an oxidizer;

a fuel cell configured to react the fuel with the oxidizer to operate at a given  
power-generation rate; and

a controller configured to regulate the reaction pressure of a reactant of the group  
consisting of the fuel and the oxidizer;

10 wherein the controller is configured to regulate the reaction pressure to be less than  
one atmosphere with the aircraft at a cruise altitude and the fuel cell operating at the given  
power-generation rate.

2. The aircraft of claim 1, wherein the cruise altitude is in the range of 55,000 to  
15 70,000 feet.

3. The aircraft of claim 1, wherein the reaction pressure of the reactant is not greater  
than 11 psia.

20 4. The aircraft of claim 1, wherein the reaction pressure of the fuel is not greater than  
11 psia, and wherein the reaction pressure of the oxidizer is not greater than 11 psia.

5. The aircraft of claim 1, wherein the reaction pressure of the reactant is not greater  
than 10 psia.

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6. The aircraft of claim 1, wherein the reaction pressure of the fuel is not greater than 10 psia, and wherein the reaction pressure of the oxidizer is not greater than 10 psia.

7. The aircraft of claim 1, wherein the reaction pressure of the reactant is not greater than 6 psia.

8. The aircraft of claim 1, wherein the reaction pressure of the reactant is approximately 6 psia and the cruise altitude is in the range of 55,000 to 70,000 feet.

9. The aircraft of claim 1, wherein the controller is further configured to regulate the reaction pressure of the reactant in response to the power requirements of the aircraft.

10. The aircraft of claim 1, wherein the oxidizer source comprises an inlet for ambient air and a compression mechanism configured to compress the ambient air.

11. The aircraft of claim 10, wherein the controller is further configured to regulate the reaction pressure of the oxidizer by regulating the amount by which the compression mechanism compresses the ambient air.

12. The aircraft of claim 1, wherein the fuel source comprises a hydrogen tank containing liquid hydrogen, and a heat source for controllably boiling the liquid hydrogen.

13. The aircraft of claim 12, wherein the controller is further configured to regulate the reaction pressure of the fuel by regulating the rate at which the heater boils the liquid hydrogen.

5 14. The aircraft of claim 1, wherein the controller is further configured to regulate the reaction pressure of the fuel to be no greater than a predetermined increment above the reaction pressure of the oxidizer.

15. The aircraft of claim 1, wherein:

10 the oxidizer source comprises an inlet for ambient air and a compression mechanism configured to compress the ambient air;

the fuel source comprises a hydrogen tank containing liquid hydrogen, and a heat source for controllably boiling the liquid hydrogen; and

15 the controller is further configured to regulate the reaction pressure of the oxidizer by regulating the amount by which the compression mechanism compresses the ambient air, and to regulate the reaction pressure of the fuel by regulating the rate at which the heater boils the liquid hydrogen; and

20 the controller is further configured to regulate the reaction pressures of the fuel and the oxidizer such that the power-generation rate of the fuel cell varies in response to the power requirements of the aircraft, and the reaction pressure of the fuel is no greater than a predetermined increment above the reaction pressure of the oxidizer.

16. The aircraft of claim 15, wherein, with a cruise altitude in the range of 55,000 to 70,000 feet, the reaction pressure of the oxidizer is approximately 6 psia, and the predetermined increment is approximately 4-5 psi.

5 17. An aircraft, comprising:

a hydrogen source including a hydrogen tank and a mechanism configured to regulate delivery of hydrogen from the hydrogen tank;

an oxygen source including a compression mechanism configured to compress ambient air from outside of the aircraft;

10 a fuel cell configured to react hydrogen from the hydrogen tank with oxygen from the compression mechanism to generate power; and

a control system configured to control the operation of the hydrogen source and the oxygen source at a given aircraft flight condition such that the fuel cell reacts oxygen at a first reaction pressure with hydrogen at a second reaction pressure, wherein the first  
15 reaction pressure is less than one atmosphere, and wherein the difference between the first reaction pressure and the second reaction pressure is no greater than a predetermined limit.

18. The aircraft of claim 17, wherein the second reaction pressure is less than one atmosphere.

20

19. The aircraft of claim 17, wherein the control system is configured to vary the first and second pressures based on power requirements of the aircraft.



20. The aircraft of claim 19, wherein the control system is configured such that at a stratospheric flight condition, the first pressure is approximately 6 psia, and the predetermined limit is not greater than 5 psi.

**IX. EVIDENCE APPENDIX**

(A) Langford, III, U.S. Patent No. 5,106,035, issued April 21, 1992.

5           Langford, III was first entered into the prosecution history by Appellants in an Information Disclosure Statement (IDS) via electronic filing, on May 25, 2004, and first cited by the Examiner in a rejection under 35 U.S.C. § 102, in an Office Action dated September 22, 2005.

10

(B) *In re Aller et al.*, 220 F.2d 454, 105 U.S.P.Q. 233 (C.C.P.A. 1955)

*In re Aller et al.*, a case cited by both the Examiner and Appellants, was first entered into the prosecution history by the Examiner in a rejection under 35 U.S.C. § 103, in an Office Action dated January 25, 2006.

15

(C) Gelfi, Sylvain; Stefanopoulou, Anna G.; Pukrushpan, Jay T.; and Peng, Huei;  
"Dynamics of Low-Pressure and High-Pressure Fuel Cell Air Supply Systems,"  
20       Proceedings of the American Control Conference, June 4-6, 2003, pp. 2049-2054,  
Denver, Colorado, USA.

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          Gelfi et al. was first entered into the prosecution history by Appellants in an Information Disclosure Statement (IDS) with an accompanying Response, dated July 24, 2006, and discussed by the Examiner in an Office Action dated October 16, 2006.

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Appl. No. 10/600,258  
Appellants' Brief, dated March 22, 2007  
In response to: Office Action, dated October 16, 2006

**X. RELATED PROCEEDINGS APPENDIX**

None.

**Document Links:**[Start of Document](#)[PRIOR HISTORY:](#)[DISPOSITION:](#)[CASE SUMMARY](#)[PROCEDURAL POSTURE:](#)[OVERVIEW:](#)[OUTCOME:](#)[CORE TERMS:](#)[LexisNexis\(R\) Headnotes](#)[COUNSEL:](#)[OPINION BY:](#)[OPINION:](#)[SHEPARD'S®](#)

42 C.C.P.A. 824, \*, 220 F.2d 454, \*\*,  
1955 CCPA LEXIS 224, \*\*\*; 105 U.S.P.Q. (BNA) 233

IN RE ALLER ET AL.

No. 6079

United States Court of Customs and Patent Appeals

42 C.C.P.A. 824; 220 F.2d 454; 1955 CCPA LEXIS 224; 105 U.S.P.Q. (BNA) 233

Oral argument January 4, 1955 March 22, 1955

**PRIOR HISTORY:** [\*\*\*1]

APPEAL from Patent Office, Serial No. 45,326

**DISPOSITION:** Affirmed.

**CASE SUMMARY**

**PROCEDURAL POSTURE:** Appellant sought a review of the decision of the Board of Appeals of the United States Patent Office rejecting appellant's application for a patent.

**OVERVIEW:** Appellant's application for a patent involved a process for the production of carboic acid as an ingredient in the production of drugs and explosives. However, the process was identical to that of the prior art, except that appellant's claims specified lower temperatures and higher sulphuric acid concentrations than were previously shown. The court affirmed a decision of the Board of Appeals of the United States Patent Office rejecting the application. The court asserted that experimentation to find the optimum conditions of temperatures and acid concentration was no more than the application of the expected skill of a chemical engineer. The court held that there was no record to support a holding of a patentable invention.

**OUTCOME:** The court affirmed the decision because the claimed process was merely different in degree and not in kind from the reference process. Moreover, appellant failed to show the criticality of the claimed ranges.

**CORE TERMS:** temperature, concentration, acid, acetone, skilled, experiment, phenol, hydroperoxide, chemist, invention, sulphuric acid, experimentation, optimum, skill, routine, reaction time, peroxide, resinification, isopropyl, solvent, specify, benzene, patentability, modification, examiner, commercially, explosive, condenser, shortened, improved

**LexisNexis(R) Headnotes** ♦ [Hide Headnotes](#)

Criminal Law & Procedure > Sentencing > Corrections, Modifications & Reductions > Eligibility, Circumstances & Factors

Patent Law > Double Patenting > General Overview

Patent Law > Jurisdiction & Review > Subject Matter Jurisdiction > Appeals

**HN1** A change in temperature, or in concentration, or in both, would be an unpatentable modification. Under some circumstances, however, changes such as these may impart patentability to a process if the particular ranges claimed produce a new and unexpected result which is different in kind and not merely in degree from the results of the prior art.

Patent Law > Jurisdiction & Review > Subject Matter Jurisdiction > Appeals  
Patent Law > Subject Matter > Products > General Overview

**HN2** Even though an applicant's modification results in great improvement and utility over the prior art, it may still not be patentable if the modification was within the capabilities of one skilled in the art.

Patent Law > Inequitable Conduct > Effect, Materiality & Scienter > General Overview  
Patent Law > Jurisdiction & Review > Subject Matter Jurisdiction > Appeals  
Patent Law > Nonobviousness > Elements & Tests > General Overview

**HN3** A reference may be valid even though it states in so many words that its disclosure is not practical.

**COUNSEL:** *Clinton F. Miller* for appellants.

*E. L. Reynolds (J. Schimmel of counsel)* for the Commissioner of Patents.

**OPINION BY:** COLE

**OPINION:** [**\*\*455**]

[**\*825**] Before GARRETT, Chief Judge, and O'CONNELL, JOHNSON, WORLEY, and COLE, Associate Judges

COLE, Judge, delivered the opinion of the court:

This is an appeal from a decision of the Board of Appeals of the United States Patent Office, affirming the rejection by the Primary Examiner of appellants' application for a patent, Serial No. 45,326, filed August 20, 1948, for "Decomposition of Organic Peroxides." Of the original sixteen claims, claims 11-14 have been withdrawn, and no claims have been allowed, all having been denied as unpatentable over a reference specifically acknowledged in the application as prior art, as hereinafter discussed.

The rejection was made upon an article appearing in the Journal of the German Chemical Society in 1944, by Heinrich Hock and Shon Lang, entitled, "Autoxidation of hydrocarbons, Report no. 9: Concerning peroxides of benzene derivatives." The reference is cited as follows:

Hock et al., Ber. Deut. Chem. Ges., 77B, pages [**\*\*\*2**] 257 to 262, 1944.

The application is for a process for the production of phenol (carbolic acid), a chemical with wide uses as an antiseptic and preservative, and as an ingredient in the production of synthetic resins, explosives, drugs, photographic developers, and dyes. Ketones (particularly acetone) are produced as by-products of the process.

Basically, the process sought to be patented involves the treatment of isopropyl benzene hydroperoxide (or similar organic peroxides) with sulphuric acid, wherein the hydroperoxide is decomposed into phenol and acetone (or other ketones). So far as pertinent to this appeal, it is not necessary to inquire into the particular chemical reactions occurring in the process, nor is it necessary to discuss the method by which isopropyl benzene hydroperoxide is formed.

The process of appellants is identical with that of the prior art, except that appellants' claims specify lower temperatures and higher sulphuric acid concentrations than are shown in the reference. (Some of the claims also specify the use of solvents, but these are better discussed separately.) The main question involved in this appeal is whether the changes in temperature [**\*\*\*3**] and in acid concentration amount to invention, or whether such changes would have been obvious to one skilled in the art.

Claim 8 was quoted by the Board of Appeals as illustrative, and reads as follows:

8. Process for decomposing isopropyl benzene hydroperoxide and the production thereby of phenol and acetone which comprises bringing said peroxides into intimate contact with aqueous sulphuric acid of a concentration between 25 and 70% at temperatures between 40 degrees and 80 degrees.

[**\*826**] The reference article shows essentially the same process as that recited in the claims, except that the only experiment discussed in the article was conducted at a temperature of 100 degrees C. and with a 10 percent sulphuric acid solution. n1

n1 Without subscribing to the accuracy of the translation, we set forth at this point the experiment as described in the reference in the following language:

Acid cleavage: 1.2 g. isopropylbenzoyl peroxide were heated with 15 ccm. 10% sulfuric acid on the reflux condenser (temperature in the tube 100 degrees, in the condenser 60 degrees. The condenser outlet was connected with a U-tube which contained about 2 ccm. water and was cooled with ice. The reaction mixture was cooled for 1 1/2 hours, 2 g. sodium hydroxide added and then filtered through a wet filter in doing which oily drops (presumably dimethyl-phenyl-carbinol were left behind. The filtrate was shaken with 1.5 g. of benzoyl chloride and the separated phenyl benzoate recrystallized from alcohol. Melting point 68-69 degrees. Yield 1.15 g. (75% of the theoretical). The mixture melting point with phenyl benzoate showed no reduction.

The aqueous solution in the U. tube showed with sodium nitroprussiate on the addition of ammonia and some solid ammonium chloride a permanganese red coloring (acetone). [\*\*\*4] [\*\*456]

The Primary Examiner held that the conditions of the claims resulted simply from experimentally varying the different factors of the process to determine the optimum reaction condition and was within the skill of the art; that there was no evidence to indicate that the reported increase in yields was a difference in kind and not of degree; that no actual commercial success had been shown; that even if commercial success had been shown, it would be insufficient of itself to show invention; and that quickened reaction times were not pertinent to show invention.

The Board of Appeals, in affirming the examiner, stated that experimentation to find the optimum conditions of temperature and acid concentration was "no more than the application of the expected skill of the chemical engineer \* \* \*." The board stated that the record did not show any significant improvement in the efficiency of the process resulting from a difference in temperature, and that the essential question was whether an increase of concentration of acid which resulted in an increase in yield was a difference of degree only, or whether it was a "difference of such magnitude as to justify the allowance [\*\*\*5] of the claims." The board held that the record failed to support a holding that there was patentable invention. An affidavit submitted by appellants after the examiner's rejection in an attempt to prove that the claimed process was "commercially attractive" while that of the reference was not, was accepted by the board only as further argumentation, and not as evidence.

[1] Normally, <sup>HN1</sup> it is to be expected that a change in temperature, or in concentration, or in both, would be an unpatentable modification. Under some circumstances, however, changes such as these may impart patentability to a process if the particular ranges claimed produce a new and unexpected result which is different in kind and not merely in degree from the results of the prior art. In re Dreyfus, 22 C.C.P.A. (Patents) 830, [\*\*827], 73 F.(2d) 931, 24 U.S.Pat.Q. 52; In re Waite et al., 35 C.C.P.A. (Patents) 1117, 168 F.(2d) 104, 77 USPQ 586. Such ranges are termed "critical" ranges, and the applicant has the burden of proving such criticality. In re Swenson et al., 30 C.C.P.A. (Patents) 809, 132 F.(2d) 1020, 56 USPQ 372; In re Scherl, 33 C.C.P.A. (Patents) 1193, 156 F.(2d) 72, 70 USPQ 204. However, <sup>HN2</sup> even [\*\*\*6] though applicant's modification results in great improvement and utility over the prior art, it may still not be patentable if the modification was within the capabilities of one skilled in the art. In re Sola, 22 C.C.P.A. (Patents) 1313, 77 F.(2d) 627, 25 U.S.Pat.Q. 433; In re Normann et al., 32 C.C.P.A. (Patents) 1248, 150 F.(2d) 708, 66 USPQ 308; In re Imscher, 32 C.C.P.A. (Patents) 1259, 150 F.(2d) 705, 66 USPQ 314. More particularly, where the general conditions of a claim are disclosed in the prior art, it is not inventive to discover the optimum or workable ranges by routine experimentation. In re Swain et al., 33 C.C.P.A. (Patents) 1250, 156 F.(2d) 239, 70 USPQ 412; Minnesota Mining and Mfg. Co. v. Coe, 69 App.D.C. 217, 99 F.(2d) 986; Allen et al. v. Coe, 77 App.D.C. 324, 135 F.(2d) 11.

Bearing in mind the foregoing, we examine the arguments of appellants to determine whether they have demonstrated patentability over the experiment of Hock and Lang.

Appellants specify three improved results from the conditions of the process sought to be patented: increased yields of phenol; increased yields of acetone; and shortened reaction times. These results, it is claimed, combine [\*\*\*7] to make appellants' process commercially attractive while that of the reference would be commercially unattractive. [\*\*457]

The yield of phenol reported by the reference article was 75 percent of theoretical, whereas the examples of appellants' specification show phenol yields of 83.7 to 100 percent. The reference did not state what acetone yield Hock and Lang obtained, although it did indicate that acetone was produced. Appellants' specification states that in following the conditions of the reference they obtained an acetone yield of about 60 percent. By their own method, appellants report acetone yields of from 71 to 88 percent, the yield, however, not being reported for two examples. The Hock and Lang reference experiment was completed in an hour and a half. Appellants' examples show comparable reaction times ranging from a total time of 20 minutes to 3 hours.

In analyzing these improved results, one is not struck by any difference in kind attributable to appellants' process - logically the improvements could flow equally well from changes in degree resulting from routine variation in temperature or acid concentration. At [\*\*828] the least efficient conditions [\*\*\*8] reported by appellants, the improvement is but a few percentage points different from the results reported by the reference. At the most efficient conditions, the improvement is still within the range of variation one might expect to result from changes in reaction conditions. There is no temperature range or acid concentration range that can really be termed "critical." As far as is shown, temperatures between 80 degrees and 100 degrees C., and acid concentrations between 10 percent and 25 percent, could result in increasingly greater efficiency, somewhat more than Hock and Lang, somewhat less than appellants. Appellants have not shown anything "critical" about their process, unless

lower temperatures and higher acidity generally are critical.

Even the affidavit of Sheffield does little more than compare the results reported by the reference and those reported by appellants, and give an opinion as to how much less costly one would be than the other. The affidavit clearly does not show commercial success. It only presents affiant's opinion that when the price of phenol is 19 cents a pound, appellants' production would be economically profitable, while that of the reference [\*\*\*9] would not. His statement is equally compatible with the theory that the improvement is a difference of degree, as it is with the theory that it is a difference of kind.

[2] However, for purposes of discussion, it may be assumed that appellants have shown an improvement over the reference, and that commercial success has been adequately demonstrated. Commercial success or improved results, however, are important only when the question of invention is in doubt. When there is no doubt that improvement resulted from routine efforts of the artisan, then commercial utility is unimportant. [3] To support a patent, it must be shown that the claimed process was not obvious to one skilled in the art, who had before him the Hock and Lang article.

Appellants contend that the claimed conditions would not be discovered by one skilled in the art, because shortened reaction times would not be expected with lower temperatures; increased resinification (and hence lower yields) of phenol and acetone would be expected with stronger acids; and greater danger of explosion would be expected at lower temperatures.

In support of the first argument, appellants state that theoretically reaction [\*\*\*10] time is doubled or trebled for each 10 degrees C. drop in temperature, while it is only shortened proportionately with an increase in the concentration of a reactant. Hence, it is argued that a skilled chemist would expect the reaction time to be inordinately lengthened by a decrease in temperature, despite an increase in the concentration of the sulphuric acid. Assuming appellants' propositions to be applicable, [\*\*\*829] it still does not follow that a skilled chemist would not try to shorten the reaction time by lowering the temperature and increasing the acid concentration. Thus, applying appellants' reasoning, at 80 degrees C. and 70 percent acid concentration (which is within the limits of [\*\*\*458] the claims) it would be expected that the reaction rate would be slowed at least four times by the temperature reduction - but that it would be accelerated seven times by the increase in acid concentration.

There is a dispute between counsel as to the validity of appellants' second assertion, that resinification should be expected with higher acid concentrations. The Solicitor for the Patent Office cited authority to show that such resinification occurs only under extreme [\*\*\*11] conditions of pressure and temperature. Appellants in a reply brief give further citation to the same authority to show the conditions were not as drastic as indicated by the solicitor. However, even taking at full value all the statements of appellants, it still appears that the reaction is a slow one, taking as long as twelve hours or more for completion, and that it is affected by temperature. There is no evidence to show that a chemist should necessarily expect that an increase in acid strength would be impracticable. As far as the evidence shows, the increased resinification due to stronger acidity might be negligible in its proportions, or it might be extensive. Experimentation would be indicated to determine the exact effect.

The third argument of appellants in this regard is that a chemist would assume that the reaction would be more likely to be explosive at a lower temperature. It is stated in appellants' brief:

A final consideration and one which is most important is the safety of the process. If the reaction time of the Hock et al. process were to be lengthened as by lowering the temperature, as the hydroperoxide is added to the acid the concentration of hydroperoxide [\*\*\*12] would increase due to the slowness of the decomposition process. There would then be great danger of the reaction becoming exothermic and causing a violent explosion. Within the limits of the appealed claims, however, the reaction may be safely carried out. [Italics quoted.]

That a reaction would be more explosive at a lower temperature goes against all common experience, and is apparently based on a gratuitous assumption that the hydroperoxide will be added to the reaction solution faster than it is being decomposed. Whether or not the general proposition is correct, there is insufficient proof of it in this record for us to reverse the concurring decisions of the tribunals of the Patent Office.

Upon reviewing all of the evidence in the case, it is evident that the contentions of appellants cannot be upheld. Hock and Lang disclosed generally the process of decomposition of isopropyl benzene hydroperoxide by sulphuric acid, with the production of phenol and [\*\*\*830] acetone. They described one experiment and its results, indicating in no way that this was the maximum yield obtainable. Any chemist reading the article could logically assume that higher yields might be [\*\*\*13] obtainable, and by experimentally varying the conditions of temperature and acidity could find the most productive conditions. If it could be held that the skilled chemist would never think to reduce the temperature or increase the acid concentration, then it might be held that invention resides in so doing. However, appellants have not demonstrated such fact. The skilled chemist who chose to experiment with the reference process would undoubtedly try the conditions defined by the claims, although he might be surprised at the extent of improvement obtained. No invention is involved in discovering optimum ranges of a process by routine experimentation. In re Swain et al., supra.

[4] Appellants suggest that the decision to experiment with the process in the first place involves invention, apparently on the theory that the process as disclosed by Hock and Lang appeared so impractical that no skilled chemist would have experimented with it. References have always been valid for what [\*\*\*459] they would convey, explicitly or implicitly, to one skilled in the art. That experimentation may not have appeared promising is of no importance. It has been held that <sup>HN3</sup> a reference may [\*\*\*14] be valid even though it states in so many words that its disclosure is not practical. In re McKee et al., 25 C.C.P.A. (Patents) 1116, 96 F.(2d) 504, 37 USPQ 613; In re Krukovsky et al., 38 C.C.P.A. (Patents) 731, 184 F.(2d) 333, 87 USPQ 110.

The Board of Appeals, in concluding its opinion, stated as follows:

\* \* \* any one in possession of the information presented by Hock et al would naturally experiment to discover optimum conditions of temperature and concentration of acid for commercial exploitation of the process. Such experimentation is no more than the application of the expected skill of the chemical engineer and failure to perform such experiments would, in our opinion, show a want of the expected skill of the engineer. \* \* \*

That we are in complete agreement with the board's reasoning is clear from the foregoing discussion.

Some of the appealed claims, as noted above, specify the use of certain solvents in the process, in addition to the temperature and acid concentration limitations. The Primary Examiner stated that the reference showed the use of solvents, and stated that the choice of a particular solvent was within the skill of the art. The Board of Appeals [\*\*\*15] affirmed this ground of rejection. Although appellants argue that this feature imparts patentability to the claims, no arguments are advanced sufficient to discredit the examiner's ruling in this respect.

It being apparent that the claimed process is merely different in degree and not in kind from the reference process, and that the criticality [\*831] of the claimed ranges has not been shown, the decision of the Board of Appeals is affirmed.

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by a simple impedance. The resistance that dominates the system impedance is higher in the low pressure system than the one observed in the high pressure system. Indeed, the high pressure air flow control system maintains the oxygen utilization during current density increments by operating on increased supply manifold pressure and thus moving between different polarization curves. The closed loop voltage observed, stays consequently almost constant during current changes. The pressure variations in the low pressure system are however very small, so a single polarization curve is used and the system impedance has the resistance of the open loop FC voltage-current circuit.

In summary, it is shown that the dynamic characteristics of the two systems (low pressure blower-based and high pressure compressor-based) are distinct and their limits in transient response arise from different subsystem interaction.

## 2 Preliminaries on FC air supply system

A brief summary of the FC model with emphasis on the subsystems with the supply manifold pressure ( $p_{sm}$ ) as the crucial parameter is presented. We then analyze the transient control authority and steady-state capabilities of low and high pressure flow devices such as blowers and compressors. The analysis is based on the high pressure FC stack model in [8] and its low pressure modification. It is assumed that the hydrogen supply system is relatively fast and the hydrogen flow rate can be instantaneously adjusted to provide minimum pressure difference across the membrane. For simplicity, we refer to the FC stack pressure ( $p_{st}$ ) which is equal to the FC anode and cathode pressure. The relative humidity of the stack inlet hydrogen and air flow is assumed to be 100%. The heat transfer effects are ignored and the temperature of the reactant flows and fuel cell stack are assumed constant at 80°C.

The blower and the compressor are sized so that the excess oxygen ratio  $\lambda$  is equal to 2, where

$$\lambda = \frac{\text{supplied rate of } O_2}{\text{reacted rate of } O_2} \quad (1)$$

The FC stack with 381 cells running at an average of 0.6 V/cell would produce about 330 A and consume approximately 252 m<sup>3</sup>/hr Air (4200 slm). High stack operating pressure assures air flow, in right proportions, in all the cathode's plates tiny channels. In addition, it improves the reaction rates, and thus, the fuel cells efficiency. Finally, it allows to reach a mass flow rate range of 0 to 0.1 kg/s despite very small dimensions of orifices. The compressor in [8] operates in a range of pressure from 1 to 4 bars.

On the other hand, the compressor needs a lot of power: 10 to 14 kW. This power is taken from the power produced by the fuel cell stack, and thus, decreases the net power actually available to propel the vehicle. The fact that the compressor is an expensive device and operates at a very high and reliability thrilling speed (around 100 kRPM) makes one wonder if it would not be better to use a cheaper and slower device such as blower to provide the air flow. Even though the FC efficiency is lower, lesser power is used to run the blower. A simple blower operates at low speed (a few thousands RPM) and very low pressure (close to the atmospheric pressure) and provides an equivalent range of mass flow rate. In this paper, we create

a model of blower, replace the high pressure compressor model by the blower model, tune and resize the system, and compare the open loop and closed loop behavior of the two fuel cell systems.

## 3 State Equations

The supply manifold (SM) model represents one lumped volume of all pipes and connections between the flow device and the FC stack. The pressure in the supply manifold,  $p_{sm}$ , is governed by mass continuity equation and energy conservation

$$\frac{dm_{sm}}{dt} = W_{fd} - W_{sm} \quad (2)$$

$$\frac{dp_{sm}}{dt} = \frac{\gamma R_a}{V_{sm}} (W_{fd} T_{fd} - W_{sm} T_{sm}) \quad (3)$$

where  $R_a = 286.9$  J/(kg·K) is the air gas constant,  $V_{sm} = 0.02$  m<sup>3</sup> is the supply manifold volume and  $T_{sm}$  is the temperature of the flow inside the manifold which is calculated from the ideal gas law and the two states ( $m_{sm}$  and  $p_{sm}$ ). The supply manifold exit flow,  $W_{sm}(p_{sm}, p_{st})$ , is calculated using a linearized nozzle flow equation (Eqn. (9)). The inlet flow  $W_{fd}$ , which is either the flow of the high speed/pressure compressor  $W_{cp}$  or the flow of the low speed/pressure blower  $W_{bl}$ , is defined in the next section.

A lumped rotational parameter model with inertia,  $J$ , is used to represent the dynamic behavior of the rotational speed of the flow device,  $\omega$ .

$$J \frac{d\omega}{dt} = (\tau_m - \tau_{fd}) \quad (4)$$

where  $\tau_m(v_m, \omega)$  is the motor torque and  $\tau_{fd}$  is the required torque from the flow device. The motor torque is a function of the motor power input,  $\mathcal{P}_m$ , and the speed,  $\omega$ :  $\tau_m = \frac{\mathcal{P}_m}{\omega}$ . The required torque of the flow device  $\tau_{fd} = \mathcal{P}_{fd}/\omega$  where the required power,  $\mathcal{P}_{fd}$ , is calculated using thermodynamic equation

$$\mathcal{P}_{fd} = C_p \frac{T_{atm}}{\eta_{fd}} \left[ \left( \frac{p_{sm}}{p_{atm}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] W_{fd} \quad (5)$$

where  $\gamma$  is the air specific heat ratio,  $C_p$  is air specific heat,  $\eta_m$  is compressor efficiency,  $p_{sm}$  is pressure inside the supply manifold and  $p_{atm}$  and  $T_{atm}$  are atmospheric pressure and temperature, respectively. Thermodynamic equations are used to calculate the air temperature leaving the flow device,  $T_{fd}$ :

$$T_{fd} = T_{atm} + \frac{T_{atm}}{\eta_{cp}} \left[ \left( \frac{p_{sm}}{p_{atm}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \quad (6)$$

In the LP system,  $\frac{p_{sm}}{p_{atm}} \approx 1$  and thus,  $T_{fd} \approx T_{atm} \approx T_{sm}$ . Therefore Equations (2) and (3) are linearly dependent and one of them can be eliminated. The LP system can, thus, be represented by two state equations:

$$\frac{dp_{sm}}{dt} = \frac{R_a T_{sm}}{V_{sm}} (W_{fd} - W_{sm}) \quad (7)$$

and (4), whereas, the HP system requires three state equations: (2)-(4).

#### 4 Flow Equations

A static compressor map is used in [8] to determine the air flow rate through the compressor,  $W_{cp}$ . The compressor flow characteristic  $W_{cp}(p_{sm}/p_{atm}, \omega_{cp})$  is from an Allied Signal compressor [3]. The map is modeled using the Jensen & Kristensen nonlinear curve fitting method [6] and the fitting result is presented in [8].

Due to the high flow rate requirement, a centrifugal blower is selected for the LP FC system. We choose the D1G133-DC13-52 from ebm Industries because there are enough information and data on the German ebm's website to build the model. It is a Dual Inlet blower of which the flow enters from both radial sides of the blower. The rotation of the impeller is obtained from an integrated 24 V DC Motor (M1G074-CF). The motor speed is controlled by changing the input voltage in a range from 16 V to 28 V. The maximum flow rate seems to be around 900 m<sup>3</sup>/h (0.3 kg/s), the maximum differential pressure is 450 Pa, and the maximum speed 2500 rpm. Figure 2 shows the values of the flow rate,  $V$ , the differential pressure,  $\Delta p_f$ , the motor power,  $P_1$ , the operating speeds,  $n$ , and the efficiency,  $\eta$ , for 10 different points based on three different voltage,  $u_m$ , inputs. We use the Fan Laws:

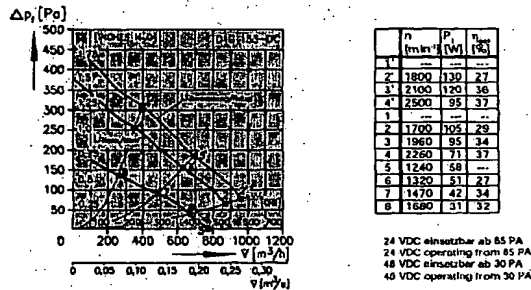


Figure 2: ebm blower-motor data

$$W_2 = W_1 \left( \frac{\omega_2}{\omega_1} \right) \quad p_2 = p_1 \left( \frac{\omega_2}{\omega_1} \right)^2 \quad (8)$$

to populate the 10 data points on four rotational speeds and fit a second order polynomial for each speed. Then we fit three forth order polynomials for each coefficient based on speed  $\omega$ . The goodness of the fit is shown in Figure 3.

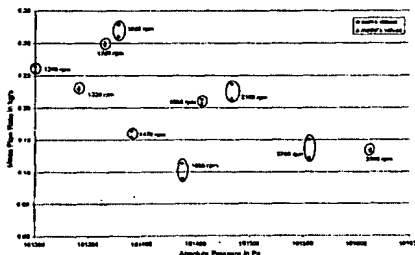


Figure 3: Data points from ebm's and model values.

For the rest of this study we use two blowers in series to double

the static pressure. It doesn't change the other characteristics and allow us to work with a larger downstream pressure.

The flow out of the supply manifold is specified by the FC flow-backpressure characteristics. We assume laminar flow:

$$W_{sm} = k_{out}(p_{sm} - p_{st}) \quad (9)$$

where  $p_{st}$  is the cathode pressure which represents the downstream pressure from the supply manifold. The nozzle constant,  $k_{out}$ , represents inverse of the flow resistance of the cathode. The value of  $k_{out}$  depends mainly on the design and the size of the air flow channels of the fuel cells. Thus, the value of  $k_{out}$  varies with different stack design.

#### 5 Low-Pressure System Equilibria and Linearization

Ideally, a linear system of the state vector  $(p_{sm}, \omega)$  is needed in order to find the eigenvalues and thus study the system transient behavior. But the system equations, especially thermodynamic equations and blower map fitting, are too complex to even find an equilibrium point for the linearization. Consideration of the operating region suggests several system simplifications.

Indeed, observation of Figure 4 shows that the blower is able to deliver a flow rate up to 0.5 kg/s whereas, the FC requires a maximum of 0.1 kg/s. Therefore, for a flow rate smaller than 0.1 kg/s we can approximate the blower flow  $W_{bl}$  with a linear relationship:

$$W_{bl} = \sum_{i=0}^1 \left( \sum_{j=0}^2 \tilde{a}_{ij} \omega^j \right) p_{sm}^i \quad (10)$$

The solid line shown in Figure 4 corresponds to the FC flow-pressure trajectory of (9) for  $p_{st}$  close to atmospheric. This trajectory is achieved during a step change in FC power and is discussed in Section 7.

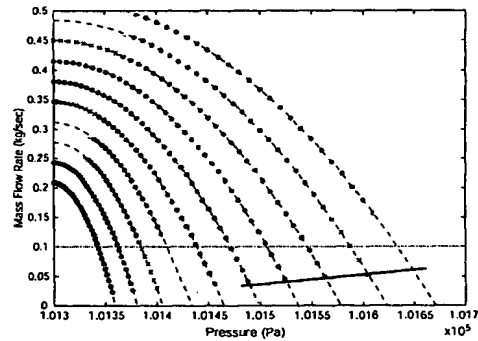


Figure 4: Blower pressure/flow map

We also simplified (5) because, in the range of pressure of our blower (101300 to 101650 Pa), the term  $(p_{sm}/p_{atm})^{\frac{\gamma-1}{\gamma}} - 1$  is linear. Thus, the blower power is calculated by

$$P_{bl} = \frac{C_p T_{atm}}{\eta} (\alpha p_{sm} + \beta) W_{bl} \quad (11)$$

where  $\alpha = 2.8198 \times 10^{-6}$  and  $\beta = -2.8565 \times 10^{-1}$ . In the high pressure case, the compressor power,  $P_{cp}$ , is calculated using Equation (5).

As mentioned above, we choose,  $p_{st} = 1.016 \times 10^5$  Pa as a reasonable pressure at the cathode exit close to the return manifold and  $P_m = 100$  Watts which corresponds to about 40 % of the single blower power (see Figure 2). The constant  $k_{out}$  is then treated as a parameter. Note that Equation (9) indicates that  $k_{out}$  can be viewed as a conductivity for an electrical circuit (inverse of a resistance), so a larger  $k_{out}$  corresponds to larger flow through the FC for a given back-pressure. A typical value of  $k_{out}$  for HP FC system is  $0.36 \times 10^{-5}$  (kg/(s·Pa)) while the value for LP FC system ranges between  $0.1 \times 10^{-3}$  and  $25 \times 10^{-3}$  (kg/(s·Pa)). The system equilibrium points  $[p_{sm}(k_{out}), \omega^o(k_{out})]$  are then calculated by solving the two nonlinear, but largely simplified, equations (2) and (4) for  $W_{bl}(=W_{fd}) = W_{sm}$  and  $P_m = P_{bl}(=P_{fd})$ . Figure 5 shows the equilibrium points for positive values of  $k_{out}$ . It is shown

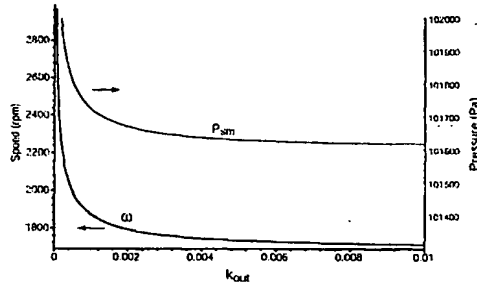


Figure 5: Equilibrium values for supply manifold pressure  $p_{sm}$  and  $\omega$  as a function of  $k_{out}$ .

that as  $k_{out}$  increases  $p_{sm}$  approaches the downstream pressure  $p_{st}$ , which is logically expected when the FC lumped flow resistance decreases. In a similar manner,  $\omega$  decreases as  $k_{out}$  increases.

The eigenvalues can be calculated from the linearized system:

$$\begin{bmatrix} \delta \dot{p}_{sm} \\ \delta \dot{\omega} \end{bmatrix} = M \begin{bmatrix} \delta p_{sm} \\ \delta \omega \end{bmatrix} \quad (12)$$

with

$$\begin{aligned} m_{11} &= \frac{RT}{V_{sm}} \left( \left[ \frac{\partial W_{fd}}{\partial p_{sm}} \right]_{p_{sm}^o, \omega^o} - \left[ \frac{\partial W_{sm}}{\partial p_{sm}} \right]_{p_{sm}^o, \omega^o} \right) \\ m_{12} &= \frac{RT}{V_{sm}} \left[ \frac{\partial W_{sm}}{\partial \omega} \right]_{p_{sm}^o, \omega^o} \\ m_{21} &= -\frac{1}{J} \left[ \frac{\partial \tau_{bl}}{\partial p_{sm}} \right]_{p_{sm}^o, \omega^o} \\ m_{22} &= \frac{1}{J} \left( \left[ \frac{\partial \tau_{sm}}{\partial \omega} \right]_{p_{sm}^o, \omega^o} - \left[ \frac{\partial \tau_{bl}}{\partial \omega} \right]_{p_{sm}^o, \omega^o} \right) \end{aligned}$$

Both eigenvalues are negative and real for all value of  $k_{out}$  as shown in Figure 6. It means that the system is overdamped for all possible value of  $k_{out}$ . But, as we can see in Figure 6, one eigenvalue is a very large that corresponds to very fast dynamics, and the other is a very small negative number that dominates the system transient response. We see that for  $k_{out}$  from 0 to 0.005,  $\lambda_1$  changes from -0.005 to -0.25 and  $\lambda_2$  changes from -6000 to -30000.

The low pressure air supply subsystem (blower and manifold) has two very different eigenvalues. Based on data from an acquired low pressure FC system,  $k_{out} = 0.42 \times 10^{-3}$  (kg/(s·Pa)),

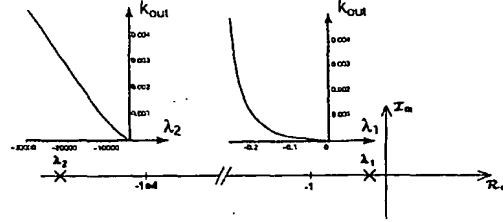


Figure 6: Eigenvalues for the LP air supply FC subsystem.

and it corresponds to eigenvalues -6035 and -0.1. Obviously, the system is composed of two subsystems which have drastically different dynamic behavior. One is very fast (eigenvalue of -6036) and the other is very slow (eigenvalue of -0.1).

### 6 Sensitivity on Parameters of the Air Supply Subsystem

It would be interesting to see the influence of the volume of the manifold and the blower inertia on these eigenvalues. Both the manifold volume and the blower inertia are design parameters that are typically defined by the vehicle designers and the blower manufacturers. Note that sometimes the supply manifold volume needs to be large due to the vehicle safety constraints that require the power electronics and electric motors to be separate from the hydrogen-rich environments ( $H_2$  tank and FC stack). Their choice has implication on the dynamic system performance because the system matrix and its eigenvalues depend of these parameters. We can plot the eigenvalues of the LP as function of the inertia (keeping constant volume) and the volume (keeping constant inertia). The results are shown in Figure 7. The nominal value of  $V_{sm}$  and  $J$  are  $0.02 \text{ m}^3$  and  $5 \times 10^{-5} \text{ kg·m}^2$ , respectively.

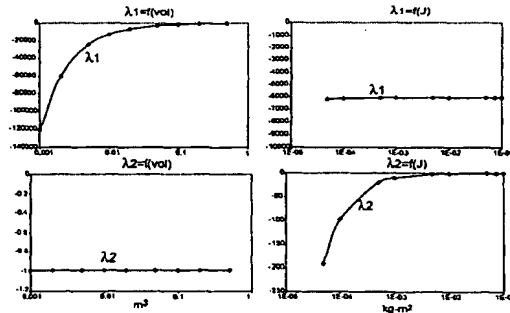


Figure 7: Influence of the Supply Manifold Volume and of the Motor Inertia on the eigenvalues ( $\lambda_1$  and  $\lambda_2$ ) of the Low Pressure System.

For the LP system, the inertia only influences the slower eigenvalue and the volume the faster eigenvalue. When the inertia decreases, the small eigenvalue increases (in absolute value). Note that the inertia does not affect the eigenvalue that correspond to the fast dynamics, but determines the dominant slow eigenvalue location. Similarly, the volume does not affect the slow dynamics but it has a large influence on the fast dynamics. We, thus, conclude that the LP second or-

der system can be decomposed to a slow "Inertia subsystem" that is determined by the blower rotational speed dynamics and a fast "Air Volume Subsystem" that is determined by the supply manifold pressure dynamics. Similarly, with practical values of volume and inertial, examination of the subspaces of each of the two eigenvectors provides corroboration for the existence of a slow (inertia) and fast (volume) subspace. For numerical (simulation with a small integration step) and analytical simplicity, one can eliminate the pressure dynamics (fast dynamics) and assume the steady-state solution of (7).

We perform the same analysis for the HP air subsystem that is based on a high speed compressor in [8]. The volume of the manifold used for the HP system is the same as the one used for the LP System :  $0.02 \text{ m}^3$ . The HP compressor inertia ( $J_{HP} = 5.10^{-5} \text{ kg}\cdot\text{m}^2$ ) is much smaller than the inertia of the LP blower ( $J_{LP} = 0.01 \text{ kg}\cdot\text{m}^2$ ). For these volume and inertia values, the eigenvalues of the HP (High Pressure) system are : -23.6, -2 and -11. There are 3 eigenvalues due to the temperature variation in the supply manifold. We see that the eigenvalues of the HP system are closer to each others than for the LP System. It means that the dynamics of the states ("pressure", "speed" and "temperature") are coupled. Figure 8 shows the influence of the manifold volume and compressor inertia on the HP System. The volume and inertia affect all three eigenvalues. Thus the state space dimension cannot be reduced and remains three.

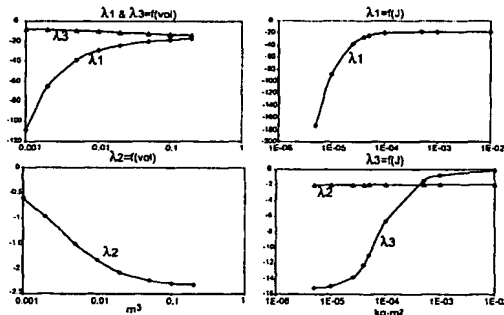


Figure 8: Influence of the Supply Manifold Volume and of the Motor Inertia on the eigenvalues of the High Pressure System.

It is important here to note that, even though the LP and the HP systems have the same manifold volume and flow rate, they have distinctly different pressure dynamics. The pressure of the LP system is a lot smaller than the one in the HP system. Moreover, the changes in pressure of the LP system are several orders of magnitude smaller than the pressure changes in the HP system during standard power steps. Pressure in the LP system remains almost constant when it is seen from the range and perspective of the high pressure system. Thus, the singularly perturbed dynamics of the LP system are physically justified. In fact when there is a step in the input of the blower motor, the pressure follows the speed to reach its final value as shown in Figure 10. It means that the system is driven by the blower inertia, and that the pressure follows the evolution of the speed very rapidly.

To have the same dynamic characteristics for the two system

(high pressure and low pressure), which means to have the same range of eigenvalues, then the inertia of the LP system has to be  $0.005 \text{ kg}\cdot\text{m}^2$  (divided by 2) and the volume of the manifold  $5 \text{ m}^3$ . Then the eigenvalues become -26 and -2, which are very close to the HP system. But such a volume for the manifold is of course not realistic. On the other hand, the value requested for the inertia is realistic and we will use that value for the rest of the study. It will be easier to compare the two systems if they have similar time constants.

## 7 Performance Comparison

In this section we compare the response of both high pressure and low pressure fuel cell systems to variations in power demand of an automotive application.

For all the comparative studies we are working with the whole fuel cell model (air supply, hydrogen supply, stack, etc). In the LP system, the constant of the linearized orifice equation between the cathode and the return manifold is chosen to be 200 times larger than that of the HP system, and the effective area of the exit pipe is the same.

First, we simulate a step change in power demand. We request both systems (HP and LP) to produce the same step of net power,  $P_{net}$ , (power produced by the stack - power used to drive the compressor/blower). The excess ratio of  $O_2$  is always kept at 2. The step is from 29 kW to 38 kW (40 hp to 50 hp). In this simulation, the static feedforward map is used to find the stack current from the desired net power,  $I_{st}(P_{net}^{des})$  and also to find the motor power input, based on the current,  $P_m(I_{st})$ , that satisfies the desired excess ratio.

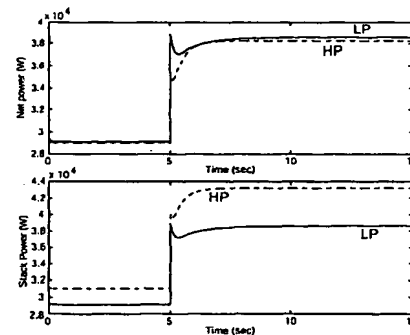


Figure 9: Net power step response for a HP and a LP FC system.

Figure 9 shows that the LP system can react a little faster than the HP system, although their slight differences can be eliminated with adequate closed loop blower controller. We also see that to obtain the same net power the HP system requires much larger power from the stack. The LP system needs less power to drive the blower than the HP system needs to drive the compressor. So at this level of net power (i) the LP system is more efficient than the HP system (ii) the LP system has a transient response similar to but a little faster than the HP system.

We can now visualize the evolution of the mass flow rate versus the static pressure for both compressor and blower. The

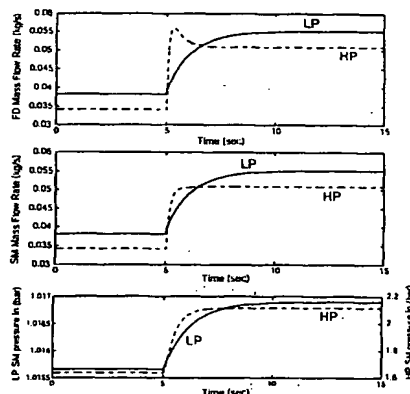


Figure 10: Pnet step : Response of the mass flow rates; upper plot shows  $W_{fd}$  lower plot shows  $W_{sm}$ .

blower is following a straight line (shown in Figure 4). On the other hand, the compressor is following an arc as shown in Figure 8 in [9] with the compressor flow growing first and a lot faster than the pressure.

In Figure 11, we show the polarization curves of the cells for both systems subjected to a ramp current demand. This is the FC voltage as a function of the current drawn in one cell when blower and compressor sustain the same excess oxygen ratio ( $\lambda_{O_2}$ ). We see that the LP system is not able to keep the same values of voltage in the cells as the HP system. So, in terms of the use of the fuel cell full potential, the LP system is less efficient.

Figure 12 shows the net power of the LP and the HP system for different current levels. In automotive applications there is a need for more investigation on the matching of these electrical and power characteristics with an appropriate traction motor and a DC/DC converter. The power-current characteristics indicate the need for a better match between the LP FC and the flow. The low pressure fuel cell "engine" would develop much less power than the high pressure one and be limited at 40 kW while the HP system's stack can produce 75 kW [9]. On the other hand, the low pressure fuel cells system is lighter, has the potential for faster response, and might be more reliable than the high pressure system. There is a compromise to find.

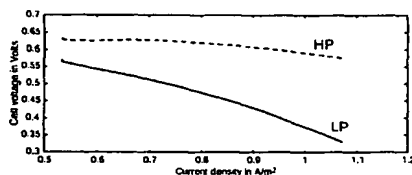


Figure 11: Polarization curves of the cells for LP and HP Systems.

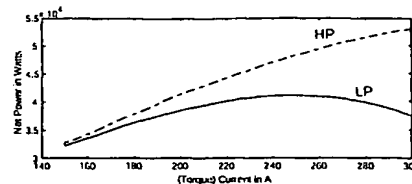


Figure 12: Net Power vs Current for LP and HP Systems.

## 8 Concluding Remarks

This paper provides a dynamics engineering perspective on the issue of FC operating pressure. It complements a significant body of work on the relative merits and difficulties between the two systems. It is anticipated that this perspective will provide insight on the system dynamics and the control implementation of FC based powertrains.

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